Sea Spray and Icing in the Emerging Open Water of the Arctic Ocean

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LONG-TERM GOALS

The goal of this project is to develop the capability to quantify both the concentration of sea spray over the open ocean and the severity of sea spray icing on fixed offshore structures. We will use existing information on the relationship of the spray concentration distribution to wind speed (Lewis and Schwarz 2004; Jones and Andreas 2012) to estimate the sea spray climatology in ice-free northern oceans from reanalysis data and the time-varying extent of the sea ice cover. Our field campaigns in the second and third years will focus on measuring sea spray parameters and relevant meteorological conditions to characterize spray drop distributions at high wind speeds and cold temperatures. Sea spray data at high wind speeds are sparse, and there are no measurements of the spray drop concentration at air temperatures below freezing. This effort directly addresses two of the focus areas in the core ONR Arctic program:

- Improving understanding of the physical environment and processes in the Arctic Ocean.
- Developing integrated ocean-ice-wave-atmosphere Earth system models for improved prediction on time scales of days to months.

OBJECTIVES

Our objectives are as follows:

- Use reanalysis data to estimate spatially and temporally distributed sea spray concentrations over the northern oceans. This estimate is currently limited by the sparse information on sea spray at high wind speeds. Adapt the Andreas et al. (2008, 2010) spray algorithms for high wind speeds and subfreezing temperatures.
- Use these estimates of sea spray concentrations to characterize the icing risk for offshore structures in northern regions by adapting the heat balance calculation for freezing rain in Jones (1996) to saline drops and by modifying the Finstad et al. (1988) collision efficiency algorithm to take into account the larger mass of saline drops compared to freshwater drops.

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- Determine the properties of sea spray in high wind speeds by making droplet concentration measurements on fixed offshore structures or at well exposed coastal sites at air temperatures below freezing.
- Measure the density of ice accreted from sea spray on fixed structures and develop a relationship between spray ice density and weather parameters.
- Use our sea spray measurements to revise the Jones and Andreas (2012) spray concentration distribution for high wind speeds; update our initial icing risk analysis.
- Rapidly disseminate all data and metadata.

APPROACH

This project is a collaboration between Andreas and Kathleen Jones of the U.S. Army's Cold Regions Research and Engineering Laboratory, who is funded under a separate award (N0001412MP20085).

Our goal is to quantify sea spray concentrations from wind-generated sea spray and the resulting spray icing on offshore structures, such as wind turbines and exploration, drilling, and production platforms. Our approach combines 1) the simulation of sea spray and icing from reanalysis data and data from moored buoys and coastal stations, 2) a field campaign to measure the liquid water content and median volume drop radius of sea spray in high winds, 3) the development of a spray concentration density function for high wind speeds, 4) the estimation of the spatial distribution of sea spray in all seasons, and 5) the determination of icing risk when the air temperature is below freezing in northern oceans.

We will use two technologies for observing spray drop concentrations during our field campaigns. The multicylinder is a stack of six aluminum, rotating cylinders with diameters varying from 0.2 cm to 7.6 cm. The collision efficiency of the wind-borne spray drops with the cylinders varies with wind speed, drop size, cylinder diameter, and air density. By measuring the water or ice collected on each cylinder along with the wind speed, exposure time, air temperature, and atmospheric pressure, we can determine the liquid water content of the spray and its median volume drop diameter, which is the diameter for which half the spray is in smaller drops and half is in larger drops. In subfreezing conditions, the multicylinder also provides icing rate data and spray ice density data.

Our second spray instrument will be a cloud imaging probe, which we are borrowing from Chris Fairall at NOAA/ESRL. This device consists of an optical array; it photographs and then automatically sizes drops moving through the array. It sizes drops with diameters from 25 μm up to 1.55 mm in 62 bins that are each 25 μm wide. The integral of the third moment of the drop concentration from the cloud imaging probe is the spray liquid water content. Hence, the combination of the two instruments provides both versatility and redundancy.

To characterize the meteorological conditions in which we observe the spray and, thereby, to develop parameterizations for spray concentration, spray production rate, and icing rate, we will also deploy a full suite of turbulence instruments. These instruments will provide mean wind speed, temperature, humidity, and pressure and the turbulent air-sea surface fluxes of momentum and sensible and latent heat—the fluxes, through eddy-covariance measurements.

The data for the spray climatologies come from the National Data Buoy Center, the National Snow and Ice Data Center, and the National Centers for Environmental Prediction.

WORK COMPLETED

We have found a site for our first winter's field campaign to measure sea spray concentration distributions, spray liquid water content, icing rates, and air-sea surface fluxes of momentum and sensible and latent heat. The site is Mt. Desert Rock in the Gulf of Maine (Figure 1), 24 miles south of Bar Harbor. The lighthouse there is farther offshore and more exposed than any other lighthouse on the east coast. Historical weather data at Mt. Desert Rock show average wind speeds in January of 10 m/s and an average air temperature of -2^{o}C. We are working with College of the Atlantic on deployment logistics. They are responsible for maintaining the facilities on the island and have ongoing research programs there.

Figure 1. Mt. Desert Rock.

We revised our multicylinder analysis program for determining liquid water content and median volume droplet diameter to handle the expected broad concentration distribution of spray drops for high wind speeds.

We downloaded historical weather data from the National Data Buoy Center (http://www.ndbc.noaa.gov/) for 26 buoys in the Gulf of Alaska for their periods of record. From these data, we will investigate how the waves are related to wind speed and other meteorological and oceanographic conditions. Remember, spray generation is closely associated with the wave field.

We downloaded relevant parameters from the North American Regional Reanalysis (NARR) 3-hourly gridded data (Mesinger et al. 2006) for 1979 and 2012. The NARR domain includes the western half of the Arctic Ocean. We developed procedures and software for preprocessing the NARR GRIB files to extract ASCII data and to merge it into winter time series for the domain. We wrote software to estimate preliminary sea spray concentration distributions and icing rates where the sea ice concentration is less than 15% using the NARR parameters and sea ice concentration time series (Cavalieri et al. 1996).

Figure 2 shows a sample of this analysis for 0900 on 16 October 1979 for the northern seven-eighths of the NARR domain. Very high winds (greater than 25 m/s) over the North Atlantic near the southeast coast of Greenland (Figure 2a) caused high spray liquid water content (Figure 2b). Windy conditions persisted for two days in that area. If the air temperatures (Figure 2c) had been just a few degrees cooler, the sea spray would have coated any offshore structure in that area with a thick layer of ice. Associated support vessels attempting to power through the wind and waves would have been even more severely impacted by the freezing spray.

RESULTS

Because the funding for this project arrived quite late in the fiscal year (Jones received hers in mid-February 2012; and Andreas, not until late June 2012), we have no conclusions or new capabilities to report. We have been analyzing reanalysis data to provide a sea spray climatology and preparing for a field program in January 2013, during which we will measure sea spray in cold and windy conditions.

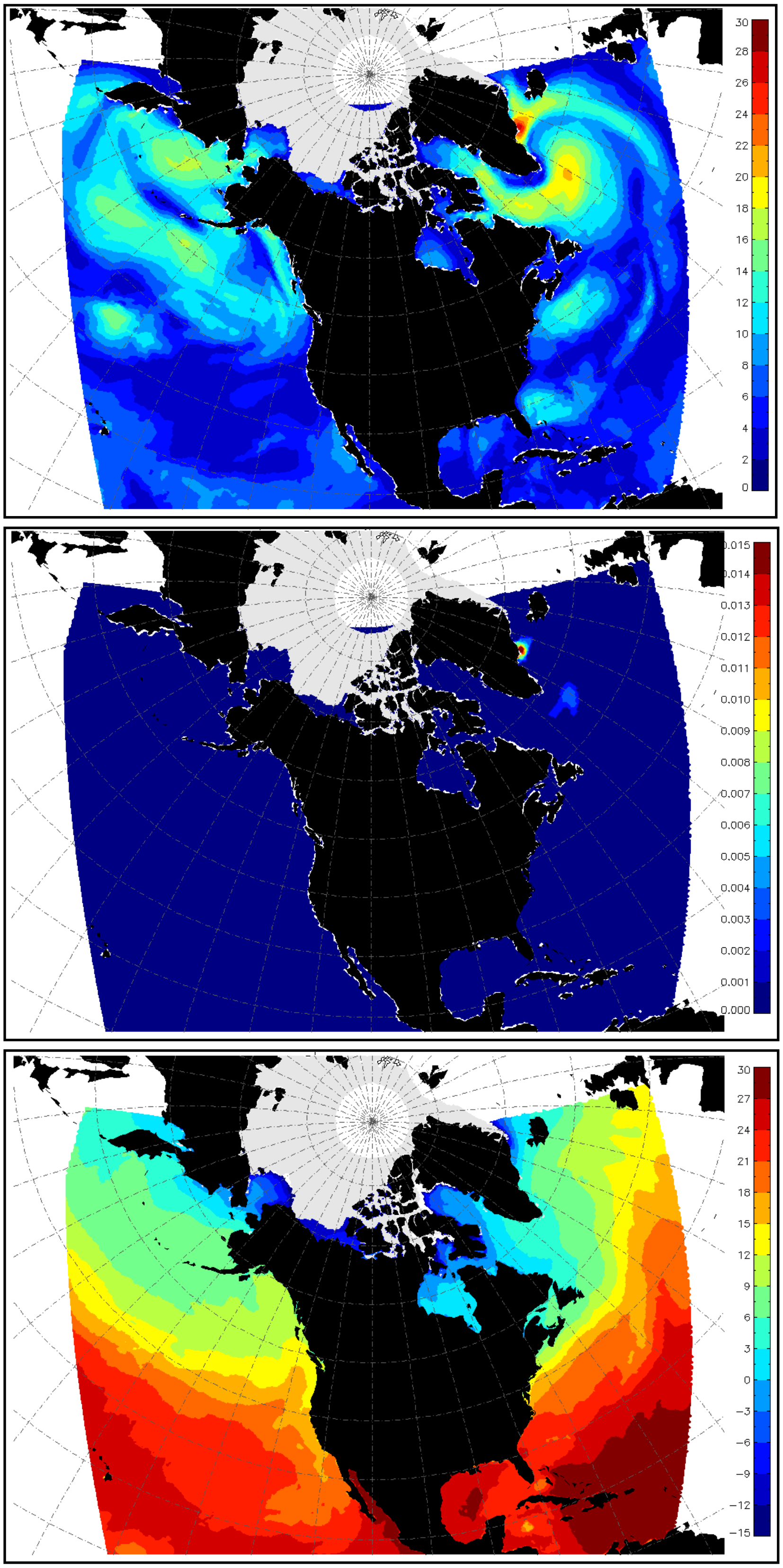

Figure 2. Contours of a) 10-m wind speed (m/s), b) 10-m sea spray liquid water content (g/m^3), and c) 2-m air temperature (^{o}C) at 0900 on 16 October 1979 over the ocean in the NARR domain. The sea ice extent (concentration greater than 15%) is superimposed in gray in the central Arctic.

IMPACT/APPLICATIONS

- We are developing a sea spray climatology over the northern oceans. Sea spray impacts both fixed offshore structures and ships. We expect the sea spray climatology in the Arctic Ocean to change with the declining sea ice cover.
- The evaporation of the drops in the marine boundary layer affects the heat and mass transfer across the air-sea interface, which in turn influences climatology. Global climate models are sensitive to changes in the surface heat flux that are as small as 1 W/m^2. Spray-mediated heat fluxes are estimated to be much larger than this (Andreas et al. 2008).
- We are assessing icing risk for fixed offshore structures. When freezing spray that is generated by the interaction of wind and waves accumulates on such structures, it is a hazard for both personnel and the structure itself. The Navy, in its role of search and rescue, needs the ability to forecast such hazards.

RELATED PROJECTS

Andreas is in the third and final year of a project funded under the National Ocean Partnership Program. This project is on "Advanced Coupled Atmosphere-Wave-Ocean Modeling for Improving Tropical Cyclone Prediction Models," with Isaac Ginis at the University of Rhode Island and Shuyi Chen at the University of Miami as lead PIs. Andreas is a subcontractor to the University of Rhode Island and has been supplying code and expertise to help the project understand surface momentum and heat exchange in hurricane-strength winds—especially spray-mediated exchange.

Andreas is in the second year of another ONR project funded by the Marine Meteorology Program: "Predicting the Turbulent Air-Sea Surface Fluxes, Including Spray Effects, from Weak to Strong Winds." In that project, he has been collaborating with Larry Mahrt and Dean Vickers, who is a subcontractor, to develop a bulk flux algorithm from a large air-sea flux dataset that they have assembled as part of the project. A bulk flux algorithm can be used in large-scale models to couple the atmosphere to the sea by providing the flux boundary conditions on the air-sea exchanges of momentum and sensible and latent heat. The turbulent flux data that we will collect under the current project can augment the data already assembled under this Andreas-Mahrt project.

REFERENCES

Andreas EL, Persson POG, Hare JE. 2008. A bulk turbulent air-sea flux algorithm for high-wind, spray conditions. *J. Phys. Oceanogr.* **38**: 1581–1596.

Andreas EL, Jones KF, Fairall CW. 2010. Production velocity of sea spray droplets. *J. Geophys. Res.* **115**: C12065, DOI: 10.1029/2010JC006458.

Cavalieri D, Parkinson C, Gloersen P, Zwally HJ. 1996. updated yearly. *Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data*, *October 1979*. Boulder, Colorado USA: National Snow and Ice Data Center. Digital media.

Finstad KF, Lozowski EP, Gates EM. 1988. A computational investigation of water droplet trajectories. *J. Atmos. Oceanic Technol.* **5**: 160–170.

Jones KF. 1996. Ice accretion in freezing rain. *CRREL Report 96-2*, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, 23 pp.

Jones KF, Andreas EL. 2012. Sea spray concentrations and the icing of fixed offshore structures. *Quart. J. Roy. Meteor. Soc.* **138**: 131–144.

Lewis ER, Schwartz SE. 2004. *Sea Salt Aerosol Production: Mechanisms, Methods, Measurements, and Models—A Critical Review*. Geophysical Monograph 152, AGU: Washington, DC, 413 pp.

Mesinger F, DiMego G, Kalnay E, Mitchell K, Shafran PC, Ebisuzaki W, Jovic D, Woollen J, Rogers E, Berbery EH, Ek MB, Fan Y, Grumbine R, Higgins W, Li H, Lin Y, Manikin G, Parrish D, Shi W. 2006. North American Regional Reanalysis. *Bull. Amer. Meteor. Soc.* **87**: 343–360.

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